Publication No. 05-003-045

ENVIRONMENTAL CONTAMINANTS IN BIRDS: PHOSPHATE-MINE AND NATURAL WETLANDS

Prepared by
University of Florida,
Department of Wildlife and Range Sciences

under a grant sponsored by the
Florida Institute of Phosphate Research
Bartow, Florida

November, 1986

FLORIDA INSTITUTE OF PHOSPHATE RESEARCH

ENVIRONMENTAL CONTAMINANTS IN BIRDS:
PHOSPHATE-MINE AND NATURAL WETLANDS

FINAL REPORT

Timothy E. O'Meara, Wayne R. Marion, Charles E. Roessler,
Genevieve S. Roessler, Henri A. Van Rinsvelt, and Orrin B. Myers

Department of Wildlife and Range Sciences
University of Florida
Gainesville, FL 32611

Prepared for

FLORIDA INSTITUTE OF PHOSPHATE RESEARCH
1855 West Main Street
Bartow, Florida 33830

Contract Manager: David J. Robertson

PERSPECTIVE

David J. Robertson, Ph.D.

Florida Institute of Phosphate Research

Uranium is usually found associated with sedimentary phosphate deposits, and the phosphate ore mined extensively in Florida is no exception. The uranium generally is present as a sparingly soluble component of the matrix that is released in quantity only during the manufacture of phosphoric acid. Nonetheless, some uranium is mobilized from phosphate matrix into groundwater. In addition, the uranium associated with phosphate is not in equilibrium with its "progeny" or "daughter" radioisotopes. The uranium daughters that form during the process of radioactive decay may be more soluble than the parent and dissolve in groundwater, they may be physically ejected by recoil when nuclear disintegration occurs, or they may exist in a different state, such as radon gas, which diffuses away. Although the uranium itself is sequestered from the biosphere because of its low solubility, several of the decay products are more problematic.

The isotope of most concern is radium-226. Biogeochemically, radium behaves like calcium, an integral component of vertebrate skeletons. Radium-226 decays through several short-lived isotopes to radon-222. The chemical reactivity of radon is of little inherent concern because it has a short half-life and for all practical purposes is inert. But radon's decay products, particularly polonium-210 and lead-210, are reactive radioisotopes that quickly adsorb onto particulates and can be incorporated into tissue.

Small quantities of radioactive thorium-232 are also present in the phosphate ore body. Generally, thorium occurs in concentrations that are far lower than those of uranium and its progeny.

The radiological quality of reclaimed phosphate-mined land depends a great deal on the type of material that is used to fill the mining excavations. The average radium-226 activity in unaltered surface soil in Polk County, the heart of the central Florida mining district, is 0.6 pCi/g. Where the mining pits have been filled with sand tailings from the beneficiation of the phosphate matrix, the activity averages 3.2 pCi/g. Only slightly higher levels are found in areas reclaimed with overburden, where the average activity is 5.0 pCi/g. Clay settling areas have the highest radium activities, averaging 23.4 pCi/g in central Florida and 14.7 pCi/g in the north Florida mining district.

Some metallic elements were also originally deposited along with phosphate. In general, the concentrations of these elements are extremely low and they are present in forms that are only slightly soluble under most conditions. Nonetheless, a few heavy metals occur in concentrations that are high enough to have encouraged speculation on their value as a potential by-product of phosphate mineral processing. The metallic elements present in greatest concentrations are titanium, aluminum, magnesium, iron, sodium, antimony, arsenic, and tungsten. Also present, though in much lower concentrations, are barium, cadmium, copper, manganese, molybdenum, potassium, rhenium, and vanadium. Many of these impurities tend to be associated with the smallest fractions of the phosphate minerals. As a consequence, the phosphatic clays tend to have higher concentrations of heavy metals than the ore body in general.

Recognizing the concern over environmental issues associated with reclaimed land, and especially technologically enhanced levels of radiation, several organizations have supported or directly performed research to examine the issue. Among the most active have been the state's Department of Health and Rehabilitative Services, the Florida Phosphate Council, the Department of Environmental Engineering Sciences at the University of Florida, and the Florida Institute of Phosphate Research. To date, the Institute has provided support for 14 projects that directly address radiation. Numerous other Institute projects have radiological components as secondary issues.

The Institute's Environmental Services research program has addressed all aspects of concern over radiation, concentrating on assessment and mitigation of health risks to the public. The program is divided into two areas: (1) public policy and (2) safety and health. The Institute has been most active in supporting research related to health and safety issues that involve direct measurement of the radiological quality of mined land and techniques to reduce public contact with radionuclides. The Institute has funded projects dealing with indoor radon levels, surface and groundwater quality, radionuclide concentrations in natural foodchains, and radioactivity in agricultural products.

Prior to the establishment of the Institute: only one study (by the Florida Game and Fresh Water Fish Commission) had been conducted of radionuclides in wildlife inhabiting areas disturbed by phosphate mining in Florida, Therefore, when the Departments of Wildlife and Range Science and Environmental Engineering at the University of Florida approached the Institute with the concept of performing additional work, the Institute recognized an opportunity to significantly increase information on levels of radionuclides and heavy metals in waterfowl, as well as in their food items and abiotic environment.

The results of this investigation include data on the levels of nine radionuclides and 18 potential heavy metal contaminants in the tissues and skeletons of four species of waterfowl that commonly inhabit wetland areas in the phosphate mineralized regions of central and north Florida. Two of the species, wood ducks and mottled ducks, are often hunted for human sport and consumption, and therefore, represent a potential route for radionuclides to enter into the human food chain. As a result, the investigators prepared a human dose estimate based on consuming these waterfowl.

In addition, levels of the environmental contaminants were measured in the food items of the birds (when they could be identified and collected) and in the water and mud of the birds wetland habitats. Both phosphatic clay settling areas and undisturbed natural wetlands in the mining districts were sampled.

Two other projects with specific goals of developing more data on the radiological quality of reclaimed phosphate mined lands and the ecosystems that have been established on these lands have been funded by the Institute since this project originally was awarded support. In 1981, the Institute began work with Environmental Science and Engineering, Inc. of Tampa on "Ecological Considerations of Reclaimed Lakes in Central Florida's Phosphate Region" (Project #81-03-018). ESE, Inc. compared the radiological quality of reclaimed lakes with that of natural lakes in the mineralized region of central Florida. Radium levels were measured in aquatic vascular plants, zooplankton, phytoplankton, benthic invertebrates, fish, water and lake sediments. Results showed that organisms collected from reclaimed lakes accumulated radium at levels comparable to those in natural lakes in the region.

Four years later, the Institute supported the Florida Audubon Society's efforts to complement the work of earlier investigators. Audubon's project, "Multidisciplinary Study of Radionuclides and Heavy Metal Concentrations in Wildlife on Phosphate Mine and Reclaimed Lands" (Project #85-05-022), included animals that had heretofore not been examined. Audubon selected two aquatic reptiles (alligators and turtles) and one terrestrial mammal (armadillo) based on the criterion that these species have significant proportions of their mass comprised of bony tissue that would likely show elevated radium activities if, in fact, uptake were a problem. Animals from mined, phosphate mineralized, and unmineralized lands in central Florida were targeted for sampling.

The results of Audubon's analyses varied considerably between species. The alligator and armadillo bones contained only low concentrations of radium, and there were no differences between land types. Hardshell turtles did show differences depending on where they were collected. Those sampled from mining-impacted land had, on average, seven times as much radium as those from unmineralized habitats. Softshell turtles also showed location-dependent differences, with lowest activities from unmineralized land, higher levels from mineralized unmined land, and the highest activities from mined wetlands.

Radiation research funded by the Institute has covered at least a portion of all major issues that have been identified by state and environmental organizations. More research is needed in some areas such as groundwater quality and agricultural production. Other studies have indicated the relative insignificance of technologically enhanced levels of radionuclides associated with phosphate mining and processing. However, all research has emphasized the goal of reducing exposure to levels as low as reasonably achievable.

for birds inhabiting settling areas to accumulate toxic concentrations of radionuclides and trace elements from these sediments. Even with contaminant levels in sediments below recognized levels of acute toxicity, synergistic and antagonistic interactions among the elements coupled with added stress factors could be deleterious to wildlife populations (Selby et al. 1970, Truhaut 1975, Dulka and Risby 1976, Ravera 1979, Caren 1981, Fleming 1981, Mertz 1981). Harvest and consumption of contaminated waterfowl by humans may result in threats to human health as well.

Four species in 3 avian families were collected in this study to investigate bioaccumulation of radionuclides and trace elements and to evaluate potential deleterious effects for the birds and humans consuming them. The objectives were:

1. To compare radioactivity and trace element concentrations in tissues of selected avian species collected on phosphate-mine settling areas and unmined (control) wetlands.

2. To determine levels of radioactivity and trace elements in samples of 3 predominant food items for each bird species collected and examine the possibility of, and pathways of, bioaccumulation.

3. To correlate radioactivity and trace element levels in wetland substrates and water with concentrations in bird tissues.

4. To evaluate the potential for deleterious effects to wildlife and man (as a consumptive user of wildlife) resulting from radioactivity and trace elements associated with settling ponds.

The 4 species chosen for study included double-crested cormorants (*Phalacrocorax auritis*), common moorhens (*Gallinula chloropus*), wood ducks (*Aix sponsa*), and mottled ducks (*Anas fulvigula*). Double-crested cormorants are almost exclusively fish-eaters (Palmer 1976), and herbivory is the dominant feeding mode of common moorhens (Howell 1932). Both are abundant year-round on phosphate mine settling areas and unmined wetlands in Florida, making them suitable subjects for studying contamination in primary and higher level consumers. Wood ducks and mottled ducks commonly breed on phosphate-mined areas, are year-round residents, and also are commonly harvested and consumed by hunters and therefore constitute a potential pathway to humans. Common moorhens are hunted, but harvest and consumption of this species are comparatively low. For purposes of this study, we assumed that ducks constituted the principal potential pathway to humans.

METHODS

Study Areas

Two regions (northern and central) were defined, based on the distribution of subsurface phosphate-bearing strata in Florida (Brooks 1981), for selection of study areas (Fig. 1). Settling areas on Occidental Chemical Company's (OXY) Suwannee River Mine, Hamilton County, were selected in the northern region (Fig. 2). In the central region, settling areas on Noralyn and Clear Springs Mines of International Minerals and Chemicals (IMC) and Agrico's Fort Green and Payne Creek Mines were selected (Fig. 2) .

Control areas having the requisite populations of waterbirds were selected in each region (Fig. 2). Unmined wetlands as close as possible to

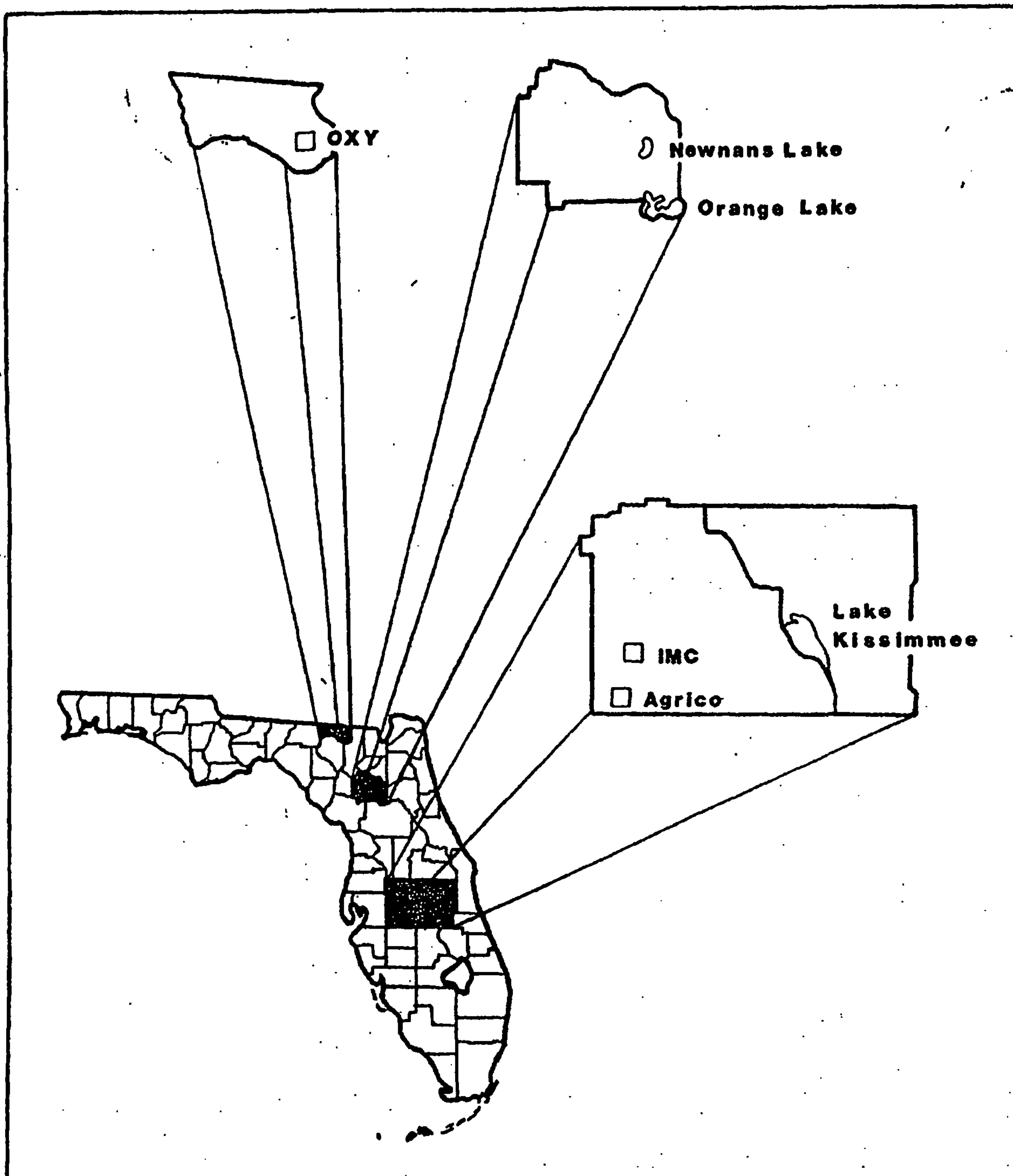

Fig. 2 Locations of study areas in Florida.

areas underlain by phoshpate-bearing strata yet distant enough from settling areas to minimize bird movements between areas were chosen. Newnans Lake and Orange-Lake, Alachua County, were selected in the northern region. The Orange Lake study area included an adjacent freshwater wetland, Right Arm Marsh. Lake Kissimmee, Osceola County, was selected as a control area in central Florida.

Sample Collection

A sample size of 20 birds of each species was sought from each of the 4 study areas (Table 1). Wood ducks and mottled ducks had natural distributions that prevented collecting 20 birds from each area. As a result, mottled ducks and wood ducks were collected in central and northern Florida study areas, respectively. Moorhen collections were limited to adults. Waterfowl and cormorant adults could not be readily and reliably selected in the field; both adults and subadults of these species were collected. All birds were collected with a shotgun using non-toxic steel shot or with a small-bore-rifle to minimize incidental tissue contamination. The major sampling intervals were from June to September, 1981 and 1982. Sixteen mottled ducks also were collected in central Florida (8 control, 8 settling) during March and April 1985 for additional radiochemical analyses.

Soft tissues (muscle, liver, and kidney) and bone tissue, including portions of the femur, tibiotarsus, and humerus, were excised from birds in the laboratory for subsequent trace element and radiological analyses. Sampling of skeletal muscle was restricted to the 2 duck species. To minimize contamination, soft tissues were removed using polystyrene knives and bone was excised using stainless-steel shears. All samples were rinsed with distilled water, placed in ethylene oxide-sterilized polyethylene bags, Annual radiation doses to individuals were estimated as the effective committed dose equivalent resulting from an intake at the average concentration of radium-226 found, assuming a conversion factor of 1.1×10^{-3} mrem/pCi ingested (adapted from International Commission on Radiological Protection 1979).

RESULTS AND DISCUSSION

Radioactivity

Radium-226. -- Radium-226 concentrations were greater ($P <: 0.05$) in substrates from settling areas than control areas in both regions (Table 2). Concentrations in substrates from control areas were within the 0.2-3.8 pCi/g range reported for natural soils in Florida (Roessler et al. 1980). Concentrations in individual samples from settling areas ranged from low values (sandy samples) comparable to natural surface soil and natural wetland substrate, to concentrations comparable to those reported for waste clays from phosphate beneficiation plants (Roessler et al. 1980).

Reported concentrations in water samples were higher for settling ponds than for control wetlands but concentrations of dissolved radium-226 were lower in all wetlands than the EPA Water Quality Standard of 5pCi/l for combined radium-226 and radium-228. A major portion of the total activity in water from settling areas was due to suspended matter. The reported concentrations of suspended and total activity may be somewhat arbitrary since the amount of suspended activity would be sensitive to turbulence of the water at the time of sampling and to the amount of disturbance caused by sample collection.

The radium-226 concentrations reported by the commercial laboratory for the submitted substrate and water samples (Table 3) were consistent with the

University of Florida results (Table 2).

Radium-226 levels in avian tissues were consistently high in bone tissue relative to levels in soft tissues (Table 2). Concentrations were below the limit of detection of the method used in many of the soft tissue samples. Radium is an alkali earth with properties parallel to those of calcium and would be expected to be sequestered in bone. As a result, radium-226 levels in bone are probably the best indicators of avian exposure to this element.

Radium-226 levels in bone tissues from all 4 species were greater ($P < 0.05$) on settling areas than control areas in both regions (Table 2). Radium-226 results from the small number of composites submitted to commercial analyses (Table 4) were consistent with the University of Florida results in that concentrations were considerably higher in bone than in soft tissues from both wetland types. Concentrations in bone from settling areas were from 4 (1981-82) to 10 (1985) times those from control areas. The concentration of radium-226 in muscle tissue collected in 1981-82 was apparently greater from settling areas than from control areas. In the 1985 samples, however, there was no difference between the composite samples from the 2 types of areas. The radium-226 concentrations were below the limit of detection in liver composites (1985) from both wetland types.

While birds in settling areas reflected the increased radioactivity of this environment, the tissue increase was not linearly proportional to the substrate increase. Ratios of radium-226 concentrations in bone relative to concentrations in substrates were lower for settling areas than control areas for all species and regions (Table 5). There may be some regulatory mechanism compensating in part for the increased amount of contaminant in settling areas resulting in a nonlinear relationship between substrate and tissue concentrations. Alternatively, settling ponds and natural wetlands to 16 pCi/kg (1985) in bone. In the settling area samples, concentrations and enhancement over the control were greatest in bone. The differences between 1981-82 samples and 1985 samples can largely be attributed to differences in reporting on an ash-weight and dry-weight basis. Muscle samples from the initial sampling episode, however, contained about 10 times the uranium concentrations measured in the 1985 samples.

Thorium-230 concentrations were below the limit of detection for bone and liver samples and this radionuclide was not taken up by these tissues in concentrations comparable to uranium. Thorium-230 appeared to be concentrated in muscle to a greater extent than in bone in the 1981-82 samples but not in the 1985 samples. The information provided by these analyses was limited by the fact that the thorium-230 analysis was approximately 1/10 as sensitive as the uranium analysis.

Lead-210 concentrations also were considerably higher in bone than in soft tissues. The concentration in the settling area bone sample was about 60% greater than, that in the control area sample in 1981-82. In 1985, concentrations in bone were comparable in magnitude to the 1981-82 concentrations (accounting for the difference between ashed and dry weights) but there was no apparent difference between the two wetland types. In muscle, concentrations were below the limit of detection in both control samples; the concentrations in settling area samples ranged from 21 pCi/kg (about twice the limit of detection) in 1981-82 to non-detectable in 1985. Concentrations in liver were the same in settling area and control samples in 1985.

Polonium-210 (1985 samples) was observed at about the same concentration as lead-210 in all bone samples from both wetland types. Polonium-210 in bone is probably present as a result of ingrowth from lead-210 rather than lifetime of the birds collected, which is a maximum of several years. However, birds exhibit greater metabolic rates than humans; it is unknown whether the observed radium concentrations in bird bone would constitute a health hazard to birds. Moreover, the fact that the concentration was 4 times that recommended for human individuals suggests that further dosimetric calculations and research on effects should be performed.

Trace Elements

Substrates. -- Fourteen trace elements were found in greater ($P < 0.05$) concentrations in substrates from at least 1 of the settling areas than in the respective controls (Table 7, Appendix C-1). Of these elements, 7 were found in greater concentrations in settling areas than control areas in northern Florida, and all 14 were found in greater concentrations in settling areas than in control areas in central Florida.

Differences in substrate concentrations between regions may have been due to structural differences in substrates as well as regional differences in element concentrations. One factor affecting trace element concentrations is soil particle size; most trace element pollution is associated with particle sizes between 0.45 and several hundred µm (Literathy and Laszlo 1976). Substrates collected from northern Florida control areas were primarily organic matter and would be expected to have more available surface area for trace element adsorption than the more sandy substrates from the central Florida control area. Also, since substrate sampling locations were based on bird collection sites rather than substrate characteristics, substrate samples differed in the relative amounts of clay and sand they contained. Fewer significant differences in northern Florida may have been due to the fact that nearly one-half of the substrate samples collected from settling areas in that region were sandy. Although settling areas showed elevated levels of several elements in relation to levels on control areas, trace element concentrations on all areas were within the ranges expected for soils and sedimentary rocks (Bowen 1966).

Water. -- Only 8 trace elements were identified in the combined dissolved and suspended fractions of water samples (Appendix C-2). Most of these were found in low concentrations, and none differed ($P > 0.05$) between the settling area and control areas in either region.

Tissues and Food Items. -- Ten elements were found in greater ($P < 0.05$) mean concentrations in avian tissue samples from settling areas than in the same tissues from the respective controls (Table 7, Appendices C-3 to C-12). Nine of these elements (Al, Br, Cu, Mn, Mo, Pb, Se, V, Zn) are slightly to very toxic to animals (Bowen 1966). With the exception of Al and Se, all were within the ranges of normal concentrations of these elements reported for animal tissues in papers summarized by Bowen (1966) and Underwood (1977). Similarly, all 9 elements, with the exceptions of MO and Al, were found in food items at concentrations below levels identified as potentially harmful in animal diets by studies summarized by the Subcommittee on Nutrient and Toxic Elements in Water (1974), Dvorak (1978), and White and Dieter (1978). Molybdenum was not identified in any of the food item samples.

Fluoride has been identified in phosphate ore (Katari et al. 1974) and water from phosphate mines (Miller and Sutcliffe 1982). Fluorine concentrates in bones and teeth and can cause fluorosis in animals (Underwood 1977). We were unable to measure F in our samples with the assay techniques used and could not assess impacts of this element on birds on phosphate-mine settling ponds. Montalbano et al. (1983), however, found no difference between concentrations of F in duck muscle from settling ponds compared to duck muscle from a control area.

Aluminum was found at elevated levels in substrates, common moorhen livers, double-crested cormorant bones, and waterfowl muscles on settling areas. Tissue levels for Al apparently have not been reported for birds in the wild. Our results of 11.9 and 6.3 ppm wet (33.0 and 25.1 ppm dry, conversion factors for converting from a dry weight to wet weight basis are in Appendix D) in moorhen livers from settling areas were at least an order of magnitude greater than the 0.4 ppm wet reported for human liver by Hamilton et al. (1972/1973, in Underwood 1977). Aluminum levels in moorhen livers also were substantially greater than the 0.03 ppm dry reported for mammalian liver by Tipton and Cook (1963, in Bowen 1966). Aluminum levels in cormorant bones from settling areas (155 and 160 ppm ash) also were greater than the levels reported by Hamilton et al. (1972/1973, in Underwood 1977) for human bones (60-73 ppm ash). Aluminum in duck muscle from central Florida settling areas averaged 12.0 ppm wet compared to 0.5 ppm in human muscle (Hamilton et al. 1972/1973, in Underwood 1977).

At high levels of intake, Al produces gastrointestinal irritation and can produce rickets by interfering with phosphate absorption. Storer and Nelson (1968, in Subcommittee on Nutrient and Toxic Elements in Water 1974) reported that 500 ppm in poultry feed can reduce growth in immature chickens. Levels of 2200 ppm in feed can cause rickets in chicks (Debold and Elvehjem 1935, in Subcommittee on Nutrient and Toxic Elements in Water 1974). Only moorhen diets on the settling area in the central region exceeded 500 ppm (Appendices E-1 to E-4). Items in moorhen diets on this area with highest levels of Al were common duckweed (*Lemna minor*, 738 ppm Al wet) and green algae (*Oedogonium* sp., 2621 ppm Al wet). These 2 food items comprised 46% of moorhen diets on this area, suggesting that Al may be potentially harmful to moorhen growth and reproduction on central Florida settling ponds.

Although Al was found in moorhen food items at levels potentially harmful to these birds, and Al levels in several bird tissues were greater than normal levels reported in the literature, there was no apparent bioaccumulation, or concentration at higher trophic levels, of this element. Ratios of Al concentrations between tissue/food and tissue/substrate were less than 1 for all tissues.

Elevated levels of Al in duck muscle tissues from settling areas apparently posed no threat to humans consuming ducks from phosphate mines. Aluminum levels in mottled duck muscles from central Florida settling areas averaged 12 ppm wet. This amount would be unlikely to cause toxicity problems for humans consuming these tissues, since human diets average 36.4 mg/day of Al in the U.S. (Hamilton and Minski 1972/1973, in Underwood 1977). For example, the intake of a person consuming 227 g (0.5 lb) of duck muscle per day with 12 ppm Al would be only 2.7 mg/day.

Selenium was found at greater levels in all liver, kidney, and muscle samples from settling areas than from control areas (Table 7). Highest mean levels found in each tissue included 22.2 ppm dry (5.8 ppm wet) in cormorant livers and 13.7 ppm dry (3.0 ppm wet) in cormorant kidneys. Levels in waterfowl muscle were greatest on central Florida settling areas (3.6 ppm dry, 1.2 ppm wet). These levels were greater than normal levels of 2.1 ppm dry in mammal muscle as reported by Dye et al. (1963, in Bowen 1966). Our results are within the range of the 5-7 ppm wet in liver and kidney and 1-2 ppm wet in muscles reached by animals at toxic levels of Se intake (Underwood 1977). However, levels of Se in food items of moorhens and mottled ducks that we sampled were well below the minimum dietary levels at which signs of toxicity will arise (3-4 ppm wet Munsel et al. 1936, in Underwood 1977), and also below the 2 ppm which Arnold et al. (1973, in Underwood 1977) found to have-no adverse effect on growth or mortality of chicks or on the production and hatchability of eggs. Selenium was not detected in water samples from any of our areas, but mean levels in substrates were all equal to or greater than 0.5 ppm. Selenium levels greater than 0.5 ppm in soil are potentially dangerous to animals (J.G. Nagy unpublished manuscript).

Unlike Al, Se concentrations increased with trophic level on the study areas. Liver/substrate ratios of Se ranged from 0.57-22 for the 4 species with only the northern control area exhibiting a value less than 1.0. Kidney/substrate Se ratios were similar to liver/substrate ratios with a range of 1.4-14. Duck muscle/substrate Se ratios also were greater than 1.0, with the exception being the northern Florida control area. Tissue/food Se ratios also indicated bioaccumulation of Se. Liver/food Se ratios ranged from 1.2-26 and kidney/food Se ratios ranged from 1.8-53 for mottled ducks and moorhens. Muscle/food Se ratios were 1.3 and 1.6 for mottled ducks from control and settling areas in central Florida, respectively.

Although Se levels in food items tested were low, tissue levels and concentration factors suggest that Se may be borderline in its toxicity to wildlife. The potential for Se toxicity problems in wildlife is greater on phosphate-mine settling areas than control areas as evidenced by the greater concentrations in soft tissue from these areas. "All degrees of Se poisoning exist, from a mild, chronic condition to an acute form resulting in death of the animal (Underwood 1977: 334)". Seleniferous diets can affect growth and reproduction as well as the health of an animal (Underwood 1977). Since the toxicity of Se varies with amounts and forms of Se ingested, duration and continuity of Se intake, and the nature of the rest of the diet (Underwood

0.05) tissue weights for cormorant livers, waterfowl kidneys, and moorhen kidneys from settling ponds. However, it is not clear that these differences in tissue weights were caused by trace element contamination. Other bird studies have shown no meaningful relationships between increased dietary metal concentrations and soft tissue masses (Cain and Pafford 1981, Haseltine and Sileo 1983) or between tissue weights and habitat conditions (Anderson 1969). Factors other than contamination may influence soft tissue weights. Sex and age differences can affect soft tissue weights, but our samples were homogeneous with respect to these demographic parameters ($P > 0.05$). Tissue weights can vary with time of year; Korschgen (1977) found eider livers were lightest after the breeding season and heaviest following a period of hyperphagia and prior to egg-laying. Tissue weights also can vary with parasite loads; Riddle (1947) found doves infested with intestinal parasites (*Ascaridia* sp.) had slightly heavier livers than non-infested birds.

No unhealthy birds were observed during the course of the study, and no evidence of pathological changes in tissues was detected. However, mortality due to chronic or acute toxicity problems is hard to detect in wild populations. Sick and moribund birds are usually eliminated by predators before a terminal condition is reached. Also, sick birds seek concealment in dense cover and bird carcasses quickly decay and vanish in the wild (Bellrose 1976).

Summary

Radiation. -- Greater radium-226 levels in substrates from settling areas than from control areas were reflected in elevated concentrations in bones for all 4 species studied. Diet/substrate ratios of radium-226 were less than 1 for all species on all areas. Bone/substrate ratios differed between settling areas and control areas. Bone concentrations of radium-226 were appreciably greater in waterfowl than common moorhens, possibly due to direct ingestion of contaminated substrates by waterfowl.

Radium-226 levels in soft tissues were consistently less than those in bone. Average concentrations in duck muscle appeared to be greater in settling than control areas. However, the levels were low, variability was great, and the differences were not significant ($P > 0.05$). Concentrations of radium-226 in waterfowl meat from settling ponds do not represent an increased threat to humans relative to waterfowl meat from natural wetlands in Florida. Concentrations in meat from all areas would pose no threat to humans when evaluated in terms of the radium-226 intake limit recommended by the Standards Committee of the Florida Phosphate-related Radiation Task Force (1984).

Radiation standards for birds have not been published. It does not appear that observed radium-226 levels in bones would constitute a health hazard to birds on settling ponds, given their short life spans. However, the average bone concentration in waterfowl from settling ponds in central Florida was about 4 times the recommended maximum for humans.

Trace Elements. -- Several trace elements were found at elevated levels in substrates and bird tissues from settling areas relative to levels in substrates and tissues from control areas. Only Al and Se appeared in bird tissues from settling areas at concentrations greater than those reported as normal for other animals, and only Al was found in potentially harmful levels in food items from settling areas. Aluminum was found at greater concentrations in 2 items in moorhen diets than concentrations that have been shown to reduce growth in chickens. Selenium, but not Al, exhibited increased concentrations at higher trophic levels. Specific effects on birds

Appendix G. Radium-226 in food items.

Sampling of bird food items was designed to represent major dietary components for individual species on the study areas and not to provide a comparison of the various individual food sources. However, these data did provide some information on the radium-226 content of biota other than the 3 bird groups. Because of differing dietary compositions for the various species and locations, few direct comparisons were possible but the data could be examined for patterns. The most striking observation was that highest concentrations in plants were observed in free-floating species such as algae, bladderwort, duckweed, and hydrilla (Appendix G-1). [Although technically rooted aquatics, bladderwort and hydrilla often exist as free-floating mats (Tarver et al. 1978)]. Even in the natural system, hydrilla had nearly 1000 pCi/kg. Also of note was the fact that lowest concentrations were observed in seeds of plants collected on dry land [e.g. bahiagrass (*Paspalum notatum*), 1 pCi/kg]. However, not all terrestrial plant seeds had concentrations this low.

The radium-226 concentrations observed in various animal species are presented in Appendix G-2. Again, only a limited number of direct comparisons were possible. In the central region, concentrations in whole sunfish (*Lepomis* spp.) from settling areas were 5 times those from the control areas. It should be noted that the fish were analyzed whole. Since the radium would be expected to concentrate in the bone, concentrations in portions consumed by humans (i.e. muscle) would likely be considerably lower than for whole fish.

Concentration ratios for settling areas are summarized in Appendix G-3. These ratios should be considered as tentative because they are based on so few samples. *The highest concentration ratio from water was observed for free-floating plants,* 1.7 x 10^4 l/kg (dry weight basis). The concentration ratio for rooted aquatic plants was 10^3 l/kg relative to the water and 0.02 kg/kg relative to the substrate. It was not